# The MIT Sensor Robot: User's Guide and Technical Reference

Fred Martin

October 22, 1991

# Preface

The *MIT Sensor Robot* is a small, mobile robot designed for educational and experimental use. Its intelligence is based on a Motorola 6811 microprocessor with 32K of battery-backed memory.

The Sensor Robot was designed for maximal features while retaining a fundamentally simple design: most of the robot's sensors are soldered directly onto its single circuit board. Thus the robot has minimal connectors and is easy to construct.

The Sensor Robot is so named because it has a multitude of common robotic sensors: touch bumpers, ambient light and light direction sensing, infrared obstacle detection sensing, wheel velocity sensing, inclination sensing, and others. Optional features include a low-powered transmit/receive radio network for inter-robot communication.

The robot's single circuit board is mounted with standoffs on an aluminum frame. Underneath the chassis are the robot's mechanics and battery. The robot uses a dual geared-wheel drive that was borrowed from an inexpensive Radio Shack car for locomotion. Its power source is a small, rechargeable 6v battery.

The Sensor Robot runs the multi-tasking Interactive C software system that was developed for the MIT Robot Design Competition. This system consists of a C compiler (running on a host PC, Mac, or Unix machine) and an interpreter (running on the robot). The C compiler compiles C programs and dynamically entered expressions, and downloads them to the robot for evaluation. Thus the system gives to the user the appearance of an interactive C interpreter. The interpreter module, written in 6811 machine code, runs on the robot at all times and is capable of multi-tasking up to 32 concurrent C processes.

It is hoped that the Sensor Robot and the Interactive C software system make for a powerful yet simple to use robot development kit, which will allow students to explore ideas in robotics in a concrete, project-oriented way, and researchers to easily conduct experiments with real mobile robots.

*The Sensor Robot was designed by Fred Martin, based on the 6.270 Revision 2 Robot Controller Board created by Fred Martin and Randy Sargent.*

*The Interactive C software environment was designed and implemented by Randy Sargent with the assistance of Fred Martin.*

# Contents

# Introduction

This *User's Guide and Technical Reference* is organized into two main sections and two appendices.

The first section is the User's Guide. The section introduces the Sensor Robot by first enumerating the various features of the robot, and then explaining how to use each one. The purpose of the User's Guide is to explain how to use the robot.

The second section is the Technical Reference. This section delves more deeply into the design of the robot, explaining the architecture of the microprocessor circuit, the ways that various sensors work, and the motor control circuitry. Reading of this section should not be considered required for those who simply want to use the robot. The Technical Reference is intended to provide concrete technical information for educational purposes (for those who wish to understand better how the robot works) and as hardware documentation.

This manual assumes some familiarity with the Interactive C for the 6811 software environment. The first appendix section provides a reference for C library functions that are specific to the Sensor Robot. These functions are introduced in the User's Guide. A separate document, IC*: Multi-tasking Interactive C for the 6811*, serves as an introduction and reference to Interactive C.

The second and third appendix sections provide detailed assembly instructions for the electronics and mechanics of the MIT Sensor Robot.

# 1 User's Guide

The first part of this section presents an overview of the Sensor Robot's features. The remainder of the section then discusses each feature in detail.

## 1.1 Overview

Figures 1 and 2 illustrate the Sensor Robot's circuit board, showing positions of sensors and other components.

### 1.1.1 Sensors

Here is a list of the sensors that are used by the Sensor Robot:

**Photocells.** The robot has three photocells; two are mounted in the front facing forward to the left and right, and the third is mounted in the back, facing upward.

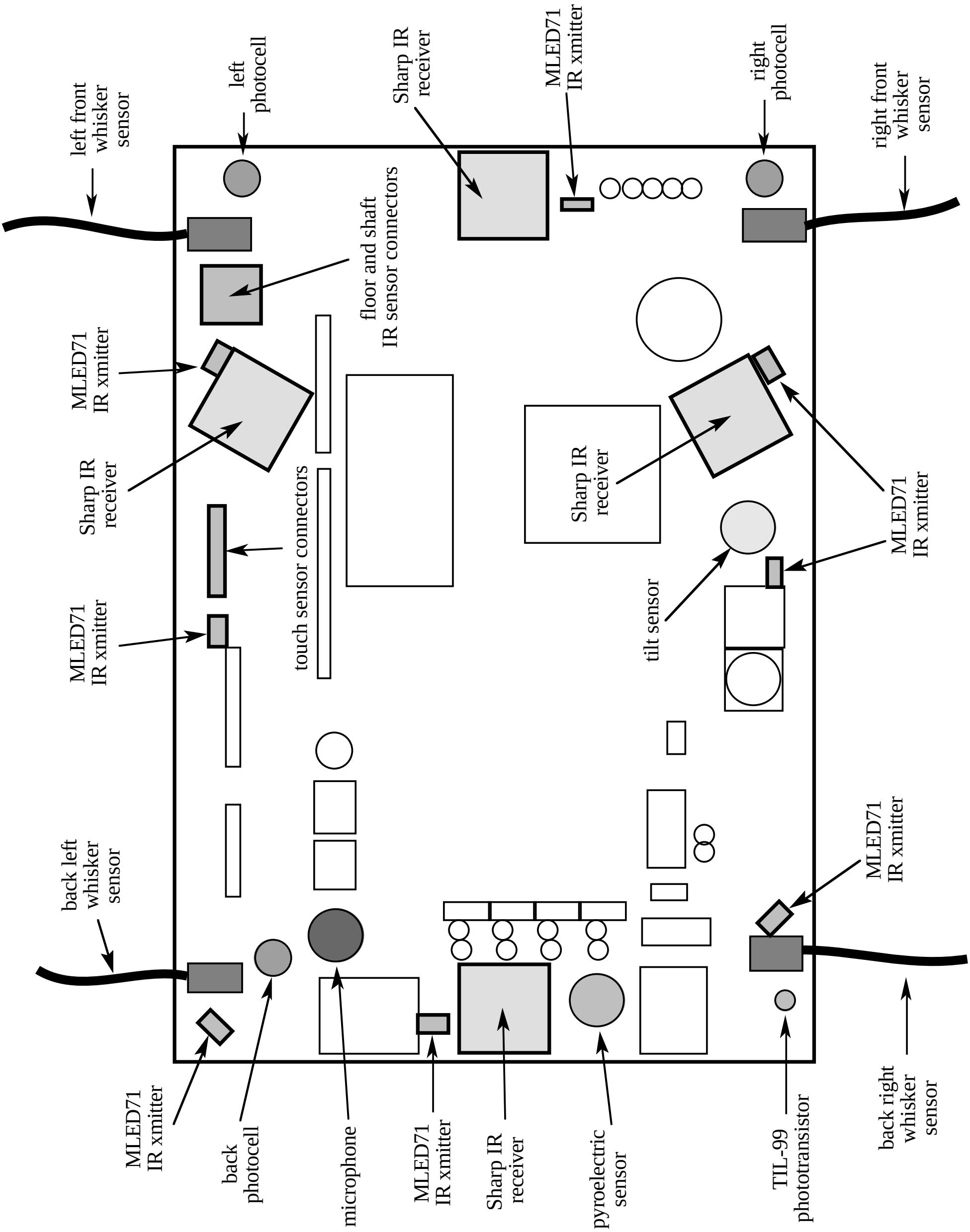
**Whisker Sensors.** A total of eight bend sensitive strips protrude from the circuit board (arranged in pairs of two). These sensors change resistance when bent, and sense when the robot brushes up against objects.

**Touch Sensors.** Mounted off-board are four touch sensors. These augment the sensing capability of the whisker sensors. The touch sensors are mounted on the left-front, right-front, and back areas of the robot's body.

**Inclination Sensor.** Labelled the "tilt sensor" on the diagram, this device provides inclination data, indicating the tilt of the robot accurate to one of eight quadrants.

**Pyroelectric Sensor.** This sensor detects the spectrum of infrared energy that is typically emitted by mammals—thus, it acts as a "person sensor."

**Front of Robot**




**Back of Robot**

Figure 1: Sensor Robot Board Sensors Layout

**Microphone.** A single microphone can detect sounds such as particular tones (generated by other robots) or an abrupt noise (such as a hand clap).

**Shaft Encoders.** Shaft encoders monitor the velocity of each of the two drive axles.

**Floor Reflectance Sensors.** Two infrared reflectance sensors determine the reflectivity of the floor underneath the robot. The sensors are mounted in left-front and right-front positions on the robot chassis.

**Infrared Obstacle Detection Sensors.** These four sensors (labelled "Sharp IRs" on the diagram) receive reflections of infrared light emitted by the eight IR emitters (labelled "infrared xmitters" on the diagram).

These sensors can also serve as a primitive inter-robot communication channel, as robots can see the infrared emissions of other robots.

**Infrared Transmission Feedback.** A phototransistor aimed at the infrared transmitters provides feedback data on how bright the modulation of the transmitters is. This brightness level can be controlled via software.

**Battery Level Sensor.** Circuitry intrinsic to the board senses the battery voltage and feeds it back to a microprocessor analog input.

### 1.1.2 Other Input and Output

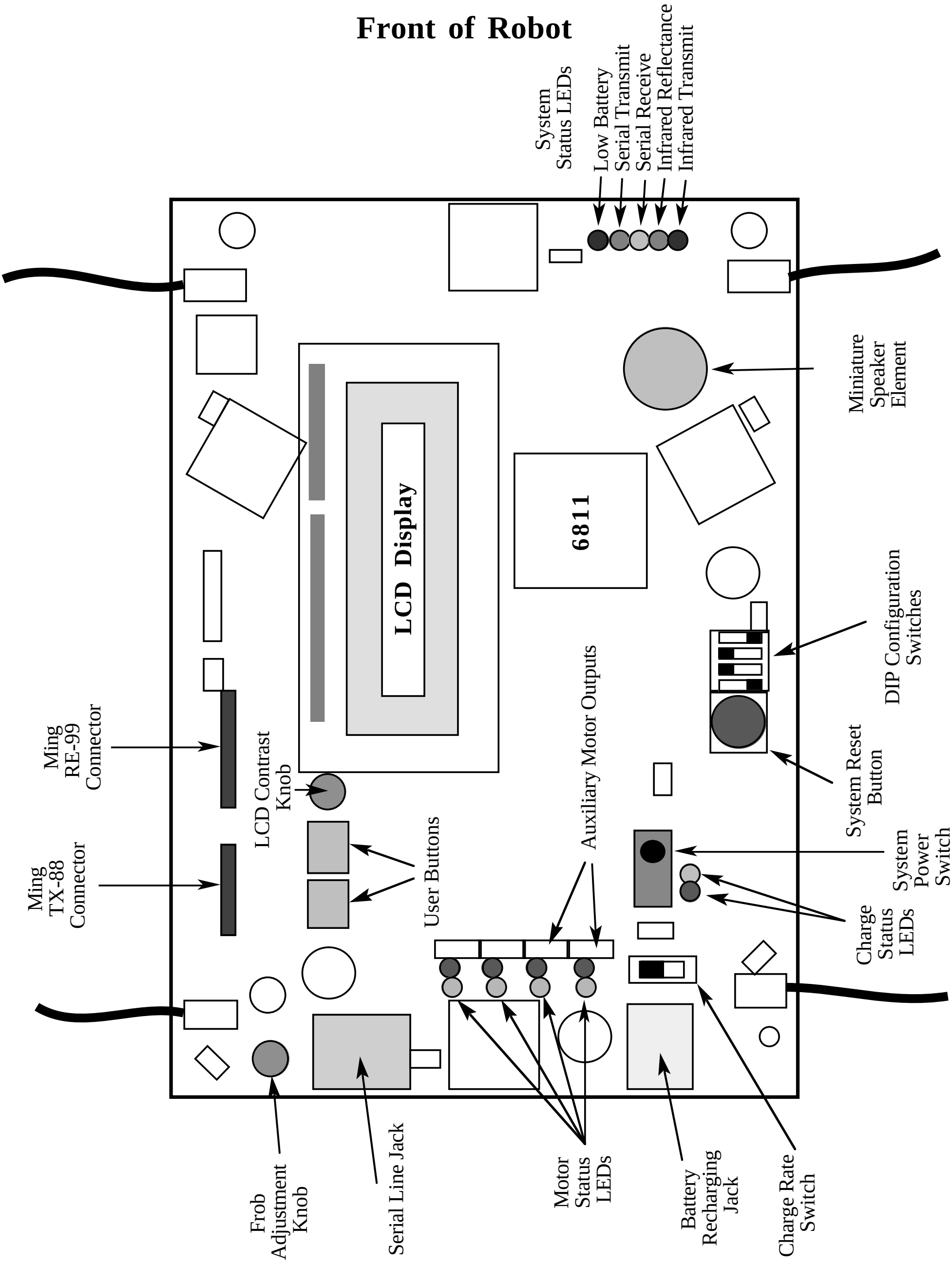
Refer to Figure 2 for location of these connectors, ports, and other devices mounted on the robot:

**On-Off Switch.** A toggle switch is used to turn the robot on and off. When the robot is turned off, the system battery provides the small amount of power necessary to retain the contents of the robot's memory indefinitely.

**Reset Button.** A red button resets the microprocessor at any time.

**Serial Port.** A 4-pin modular phone jack provides the connector for a standard RS-232 serial line. This port is used to program the robot from a host computer.

**Front of Robot**




**Back of Robot**

Figure 2: Sensor Robot Board Connectors Layout

**Battery Charge Jack.** An AC adapter is plugged into the robot to recharge its battery.

**Battery Charge Rate Switch.** A small slide switch selects one of two charging rates: a normal twelve-hour charge and a three-hour "zap" charge.

**LCD Screen.** The robot has a $16 \times 1$ character LCD screen for displaying information to the user.

**LCD Contrast Adjustment Knob.** A small knob allows contrast adjustment of the LCD screen.

**Miniature Speaker.** A tiny but loud speaker element provides another means to provide feedback to humans who may be observing the robot. Also, the speaker can be used to transmit tones to other robots listening with their microphone sensors.

**Frob Buttons and Knob.** Two pushbuttons and a "frob knob" are provided for general-purpose use as interactive input devices. For example, a menuing program may be written to display options on the LCD screen and allows the user to scroll through and select options.

**DIP Configuration Switches.** Four DIP switches may be used to select robot configuration (if several programs or modes are resident in the robot) or robot ID number (when performing experiments with multiple robots).

**Status Indicator LEDs.** A number of LEDs provide specific status information: motor state, battery charge indication, low battery indication, power on, serial receive, and infrared transmit.

### 1.1.3 Motor Control

The Sensor Robot has circuitry to bidirectionally control four DC motors. Two of these motor ports are dedicated to controlling the left and right wheels of the robot; the other two ports are available for expansion.

Through software, the power level outputted on the motor ports may be adjusted in eight graduations from off to full on. In the case of the built-in

gear drive, the shaft encoders monitoring the wheel speed are used by a servo routine to implement velocity control.

### 1.1.4 Radio Link

The Sensor Robot has a built-in interface for the adding of a radio transmit and receive board set. This board set, manufactured by Ming Electronics[1], provides a four-bit-wide data channel between robots or between robots and a human.

## 1.2 Sensors

This section explains in more detail the capabilities of each sensor and how to use the C library functions associated with it.

### 1.2.1 Photocell Sensors

Three photocells are built into the Sensor 'Bot. These measure levels of visible light, being most sensitive to the red spectrum.

Two of the sensors face out over the front of the robot; one is mounted in the back facing upward.

The library functions associated with the sensors return an integer from 0 to 255 indicating the brightness of light detected by the sensor. The *smaller* the number, the brighter the light detected.

The library functions are:

```
int left_photocell();

int right_photocell();

int back_photocell();
```

### 1.2.2 Whisker Sensors

The whisker sensor is an affectionate name for the sensor that was developed for use in the Nintendo (R) power glove. These sensors are flexible plastic strips whose resistance changes with amount of bending experienced by the sensor.

---

[1] Electronics 1 2 3, 17921 Rowland Street, City of Industry, CA 91748; (818) 913-6735

The sensors are only affected by bending in one direction from flat (the direction such that the printed side of the sensor is on the outside of the convex curve). Therefore, they are used in pairs, mounted back to back, so that the paired sensor must bend in a direction that it is sensitive to.

Four paired whisker sensors are used on the Sensor Robot, in front-left, front-right, back-left, and back-right configurations.

Reading a whisker sensor returns a value from 0 to 255, where a value near 128 indicates that the sensor is in the straight (unbent) position. Readings greater than 128 indicate the degree of bend toward the front of the robot, and readings less than 128 indicate the degree of bend toward the back of the robot.

The library functions are:

```
int front_left_whisker();
int front_right_whisker();
int back_left_whisker();
int back_right_whisker();
```

### 1.2.3 Touch Sensors

The library functions for the robot's touch sensors return the integer 1, or logical true, when depressed, and the integer 0, or logical false, when not depressed.

```
int front_left_touch();
int front_right_touch();
int back_left_touch();
int back_right_touch();
```

### 1.2.4 Inclination Sensor

The inclination sensor is a unique device consisting of a tiny gold ball enclosed inside a metal can that has four contacts. The gold ball rolls around inside the metal can, making and breaking electrical contact between the side of the can and one or two of the contacts.

Depending on the inclination of the sensor, the ball tends to rest on particular contacts. Although the ball has a tendency to bounce around due to the vibrations of the robot, probabilistic methods can be used to deduce which contact the ball is preferring at a given moment.

The library function for the inclination sensor returns a floating point number indicating the angle of inclination of the surface the robot is resting on, with respect to a line drawn from the center of the robot out through its nose. This angle is expressed in radians, and its range is $-\pi < angle \leq \pi$.

For example, if the robot's nose were elevated, the angle would be 0 radians. If the robot's butt were elevated, the angle would be $\pi$ radians. If the robot's right side were elevated, the angle would be $\frac{\pi}{2}$ radians. If the robot's left side were elevated, the angle would be $-\frac{\pi}{2}$ radians.

```
float inclination();
```

### 1.2.5 Pyroelectric Sensor

The pyroelectric sensor passively detects emissions in the infrared spectrum of the type generated by body heat.

The sensor consists of two elements. The output of the sensor is the amplified difference between the heat sensed by the two elements. Thus, the sensor detects sources of heat that *move across* the dual element (creating a differential between the left side and the right side).

### 1.2.6 Microphone

Two functions are available to process data from the microphone. The first function

```
int microphone();
```

is a "raw" reading directly from the sensor. As sound consists of sinusoidal signals, this reading will be sinusoidal and will tend to have an average value of about 128. The greater the excursions from 128 present in the signal stream, the louder the sound being received.

This value may be thresholded as a crude method to detect loud noises.

A second function

```
int loudness();
```

processes the signal stream coming from the microphone for magnitude of devation from average. The larger the value returned by this function, the louder the instantaneous noise received by the microphone.

### 1.2.7 Floor Reflectance Sensors

Two sensors provide information about the reflectivity of the ground underneath the robot. The sensors are mounted in the front of the robot, positioned slightly to the left and to the right of the center.

The reflectance sensors have controllable sources of infrared light. These sensors measure reflectivity by subtracting the sensor reading of when the IR source is off from when it is on. This method tends to remove the effects of changes in ambient light.

The library functions

```
int left_floor_reflect();
int right_floor_reflect();
```

return an integer from 0 to 255 indicating the reflectivity of the floor surface on the respective side of the robot. Smaller numbers indicate greater reflectivity.

A yellow status LED (labelled "IR REFL" on the robot board) is illuminated when the IR transmitters for the floor reflectance sensors (or the shaft encoders) are powered.

### 1.2.8 Shaft Encoders

**Basic Operation** An infrared reflectance sensor of the same type used to measure the reflectivity of the floor surface is used to track rotations of the robot's wheels. Library variables report the instantaneous velocity of the left or right wheel by the method of successive differences in rotational counts between samples.

The standard Sensor Robot has four white and four black segments on each wheel, yielding eight counter ticks per one wheel revolution. Velocity units are reported in *ticks per 64 milliseconds* (each transition from white to black or black to white on the robot wheel constitutes one tick).

A velocity reading of 8 then indicates the wheel is turning one revolution per 64 milliseconds. Since 64 milliseconds is approximately $\frac{1}{16}$th of a second,

the wheel velocity would then be about 16 turns per second. So, by doubling the readings returned by the library variables you can get a measure in revolutions per second.

The library variables reporting wheel velocity are

```
int left_wheel_velocity;
int right_wheel_velocity;
```

Note that these are references to library variables, not calls to library functions.

**Calibrating the Shaft Encoders** The shaft encoders work by measuring the difference in reflected light from the black vs. the white portions of the wheel rim that are measured by the infrared sensor. In order to be effective, a reliable differential between the black and white readings must be available.

To allow for differences in reflectivity of black pens used to mark the wheel rim, ambient light, distance from the wheel rim to the sensor, and other variables, adjustable thresholds for white detection and black detection are used. These threshold may be adjusted by user software or command-line interaction.

Typical readings from the shaft encoders are values around 5 for white reflectivity, and values between 30 and 50 for black reflectivity. The library functions `ir_encoder_left()` and `ir_encoder_right()` return the direct analog values registered by these sensors.

When the sensed value falls below a "white detection threshold," the encoder software registers a click; likewise, when the sensed value rises above a "black detection threshold" the software registers a click. The default setting for the white detection threshold is 8; the default setting for the black detection threshold is 15.

If you notice that the sensors on your robot yield a different range of readings, you may set the library variables `white_detect_threshold` and `black_detect_threshold` to new settings according to the range yielded by your sensors. (Presently, there is one set of thresholds which is used for both the left and right encoders.)

In some cases, it may be necessary to write a background process that monitors the `ir_encoder_left()` and `ir_encoder_right()` values and dynamically adjusts the threshold values.

### 1.2.9 Infrared Obstacle Detection Sensors

### 1.2.10 Infrared Transmission Feedback

### 1.2.11 Battery Level Sensor

The function

```
int battery_level();
```

returns an integer from 0 to about 100 indicating the state of charge of the system battery, where 0 is considered "near-empty" and 100 (or greater) is considered full charge.

In addition, a red status LED will light when the battery becomes discharged. Usually the robot will be incapable of running its motors before this LED will light; the LED indicates that the battery is very discharged and should be charged immediately.

Another function

```
float battery_voltage();
```

returns a floating-point number that approximates the voltage on the battery terminals. The ideal reading would be six volts (there is a one-volt drop before the battery voltage powers the digital electronics).

## 1.3 Other Input and Output

### 1.3.1 Battery Charging

To recharge the robot's battery, simply plug the AC adapter into the robot. The *red LED* located near the charge jack should light, indicating that the robot is charging.

The small slide switch located directly at the back of the charge jack is used to set the charge rate. The position nearer to the edge of the circuit board is for *normal charge*. When the robot is charging in this mode, the *green LED* ("safe charge") located near the charge jack will be lit (as well as the red "charging" LED).

Normal charge will take about five to six hours to charge the battery. When the battery begins to get warm, it is charged. A bit of warm emanating from the battery is nothing to worry about. You can leave the robot on

normal charge for overnight, but any longer than that is not good for the battery.

The other position of the charge rate switch is *zap charge.* Zap charge will fully charge the battery in about an hour. *Do not leave the battery on zap charge for more than two hours, or after the battery begins to get warm.* You will notice that the green LED turns off in the zap charge mode, reminding you not to leave the robot in this state for a long time.

### 1.3.2 Using the Speaker

Several library functions exist to let you make tones with the speaker. The first of these makes a short beep:

```
void beep();
```

To control the pitch and duration of the beep, use the `tone` function:

```
void tone(float frequency, float duration);
```

The duration is specified in seconds and the frequency in Hertz.

To create a continuous beep and modulate the pitch, use the following three functions:

| | |
|---|---|
| `void beeper_on();` | to start beeping, |
| `void set_beeper_pitch(float frequency);` | to change the tone, and |
| `void beeper_off();` | to stop beeping. |

There is no provision for controlling the volume of the beeper.

### 1.3.3 Frob Inputs

Simple menuing programs using these library functions can easily be written to take advantage of the combinations of the frob buttons, knob, and LCD screen.

| | |
|---|---|
| `int frob_knob();` | returns an integer from 0 to 255 indicating the rotation of the knob. |
| `int choose_button();` | returns 1 if the button is pressed and 0 if not. |
| `int escape_button();` | returns 1 if the button is pressed and 0 if not. |

### 1.3.4 DIP Configuration Switches

The library function `int dip_switches();` returns an integer from 0 to 15 corresponding to the binary number set on the DIP switches. The left-most switch position (labelled "1" on the switch) is the most significant digit of the binary number. The position labelled "Open" is a binary one; the other position is the binary zero.

The library function `int dip_switch(int n);` returns the value of DIP switch `n`, where `n` is 1, 2, 3, or 4 (corresponding to the markings on the switch).

## 1.4 Motor Control

There are several different "levels of abstraction" provided to control the motors on the Sensor Robot:

- **Direct motor control.** Individual motors may be turned on and off, or set to operate at a particular power level.
- **Robot-level motor control.** Abstractions to command the robot to move forward, backward, or turn (at varying power levels) are provided.
- **Motor velocity control.** You may provide a velocity setpoint to a software feedback control loop that controls the velocity of the left and right motors on the robot.

### 1.4.1 Direct Motor Control

Motors are numbered `0`, `1`, `2`, and `3`. They may be set in a "forward" direction (which corresponds to the motor LED being lit green) and a "backward" direction (which corresponds to the motor LED being lit red). On the Sensor Robot, motor 0 is the left-wheel motor, and motor 1 is the right-wheel motor.

The functions `fd()`, `bk()`, and `off()` provide simple control of motor state, turning a motor on in the forward direction, on in the backward direction, or off, respectively.

In addition, the power level of motors may be controlled. This is done by strobing a motor on and off rapidly (a technique called *pulse-width modulation*. The `motor()` function allows you to control a motor and set its power

level. Powers range from `100` (full on in the forward direction) to `-100` (full on the the backward direction). The system software actually only controls motors to seven degrees of power, but limits of -100 and +100 are given for ease of use.

`void fd(int m)`
Turns motor `m` on in the forward direction. Example: `fd(3);`

`void bk(int m)`
Turns motor `m` on in the backward direction. Example: `bk(1);`

`void off(int m)`
Turns off motor `m`. Example: `off(1);`

`void alloff()`

`void ao()`
Turns off all motors. `ao` is a short form (easy to type!) for `alloff`. Example: `ao();`

`void motor(int m, int p)`
Turns on motor `m` at power `p`. Powers range from `100` for full on forward to `-100` for full on backward.

### 1.4.2 Robot-Level Motor Control

Six functions to command the robot have been built from the direct motor control functions. These take as input the desired power level to command the robot.

`void robot_forward(int power)`
Makes the robot go forward at power level `power`.

`void robot_backward(int power)`
Makes the robot go backward at power level `power`.

`void robot_right(int power)`
Makes the robot turn right (left wheel on, right wheel off) at power level `power`.

`void robot_left(int power)`
Makes the robot turn left (right wheel on, left wheel off) at power level `power`.

`void robot_spin_right(int power)`
Makes the robot spin in place clockwise (left wheel on forward, right wheel on backward) at power level `power`.

`void robot_spin_left(int power)`
Makes the robot spin in place counter-clockwise (right wheel on forward, left wheel on backward) at power level `power`.

### 1.4.3 Motor Velocity Control

The software feedback control loop is enabled by setting the library variable `velocity_control_enable` to a non-zero value:

```
velocity_control_enable= 1;
```

(The default setting for the variable is off.) When enabled, the robot's left and right wheels are controlled by the feedback loop. The library variables `left_velocity_setpoint` and `right_velocity_setpoint` can then be set with the desired speeds. For example, the following commands

```
left_velocity_setpoint= 3;
right_velocity_setpoint= 3;
```

will make the robot go approximately forward at a speed of six wheel revolutions per second.

In addition to controlling the velocity, you can control the power level applied to the wheels during the feedback control function. The default settings are 50%, but this value may need to be adjusted higher to achieve greater speeds or speeds on difficult surfaces.

To do this, use the `motor()` functions mentioned earlier. When velocity control is enabled, these functions modify only the power level used by the velocity control routine, not the actual on-off state of the motor.

To turn the robot's motors off when in velocity control mode, set the left and right velocity setpoints to zero. The function `alloff()` may also be used to perform this operation.

# A C Library Function Handy Reference

## Version 1.0 March 6, 1994

### Photocells

```
int left_photocell();
int right_photocell();
int back_photocell();
```

### Whisker Sensors

```
int front_left_whisker();
int front_right_whisker();
int back_left_whisker();
int back_right_whisker();
```

### Touch Sensors

```
int front_left_touch();
int front_right_touch();
int back_left_touch();
int back_right_touch();
```

### Inclination Sensor

```
float inclination();
```

### Pyroelectric Sensor

### Microphone

```
int microphone();
int loudness();
```

### Floor Reflectance Sensors

```
int left_floor_reflect();
int right_floor_reflect();
```

### Shaft Encoders

```
float left_wheel_velocity;
float right_wheel_velocity;
```

### User Buttons and Knob

```
int choose_button();
int escape_button();
int frob_knob();
```

### Tone Control

```
void beep();
void tone(float frequency, float duration);
void set_beeper_pitch(float frequency);
void beeper_on();
void beeper_off();
```

### DIP Configuration Switches

```
int dip_switch(int switch);
int dip_switches();
```

### Battery Level Sensor

```
int battery_level();
float battery_voltage();
```

### Motor Control

```
void fd(int motor_number);
void bk(int motor_number);
void off(int motor_number);
void motor(int motor_number,
    int speed);
void ao();
```

### Robot Control

```
void robot_forward(int speed);
void robot_backward(int speed);
void robot_left(int speed);
void robot_right(int speed);
void robot_spin_left(int speed);
void robot_spin_right(int speed);
```

# B Electrical Assembly Guide

These assembly instructions assume that you already know how to mount and solder components onto a circuit board. If you do not, please get help from a friend or from detailed beginner's instructions before attempting to assemble the robot board.

*Read these instructions through from start to finish* before *beginning to assemble your robot.*

These instructions do not give you step-by-step directions for each and every little part on the circuit board. They make the assumption that you can locate parts, determine their value, and mount them properly more or less on your own. Instead, the instructions give you

1. an overall sequence you should use to assemble the board;
2. details of exceptional, weird, or otherwise non-obvious cases of component mounting.

## B.1 Conventions

There is quite a bit of order and reason in the layout and labelling of the components on the board. Here I will explain the conventions that have been used.

### B.1.1 Component Polarity

Most of the conventions have to do with *component polarity.* Polarity is the concept that if you install something backwards it will not work. Most electronic components, such as diodes, transistors, and integrated circuits, are polarized. Resistors are an example of a non-polarized component. Large capacitors (typically, ones larger or equal to 1 $\mu$F, are polarized, while small ones are not.

These are the standardized polarization markings on the Sensor Robot Board:

**Integrated Circuits.** The polarization of IC's is marked in two ways. First, a square metal pad on the both sides of the board indicates the pin one

position on the IC. Second, a notch in the outline drawing of the DIP package indicates the orientation of the corresponding notch on the IC. *Mount the IC sockets so that the notch on the socket is aligned with the notch drawn on the board.*

**Capacitors.** The **square metal pad on the board** where a capacitor mounts indicates the **minus lead**.

Capacitors themselved are marked in several ways. Sometimes, the minus lead is marked; sometimes the positive lead is marked. *Look closely at all polarized capacitors to determine the marking.*

The board has a square pad marking even if the capacitor itself is non-polarized; in this case, the board marking can be ignored.

**LEDs.** The square pad on the board indicates the minus lead. LEDs themselves are marked with short and long leads. In most cases (and in all cases of the LEDs we are using), the **short lead is minus**, and goes into the square hole.

**Diodes.** The square hole indicates the minus (or cathode) lead. The diode is marked with a band that is closer to one end than the other: this band indicates the cathode or minus lead. For diodes that can be mounted flat, the diode should be mounted such that its banded end aligns with the band drawn on the board.

**Resistor Packs.** While single resistors are non-polarized components electrically, some types of resistor pack have a non-symettric internal configuration (for example, a common terminal). All but one of the resistor packs used on the Sensor Robot are of this variety.

On the resistor pack, the common lead is marked with a dot or band. On the board, this pin mounts in the square hole. Additionally, the outline drawn for the resistor pack has a band to enclose this square pin with a box.

### B.1.2 Flat Mounting versus Upright Mounting

When mounting components, the general rule is to try to mount them as closely to the board as possible. The main exception are components that

must be folded over before being soldered; some capacitors and sensors fall into this category.

You will notice when assembling the board that most resistors and diodes must be mounted upright while others may lay flat. The rule: go with the flow. If space has been provided to mount the component flat, then do so, and try to keep it as close to the board as possible. If not, then just bend one lead over parallel to the component, and mount the component tightly.

See Figures 3 and 4 for clarification.

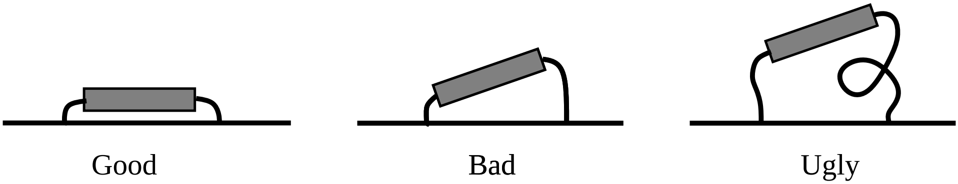



Figure 3: Flat Component Mounting

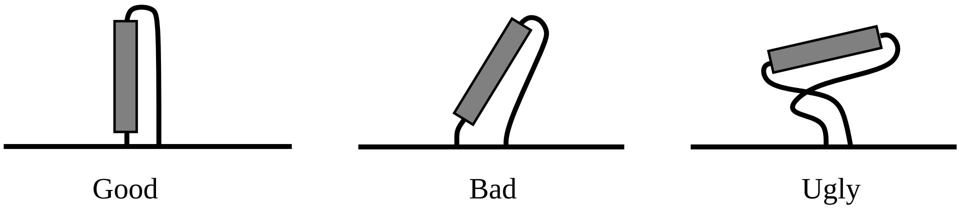



Figure 4: Upright Component Mounting

## B.2 Assembling the Board

Have all your tools ready—your soldering iron heated up, a sponge to clean the iron, and a tool to clip component leads—before beginning.

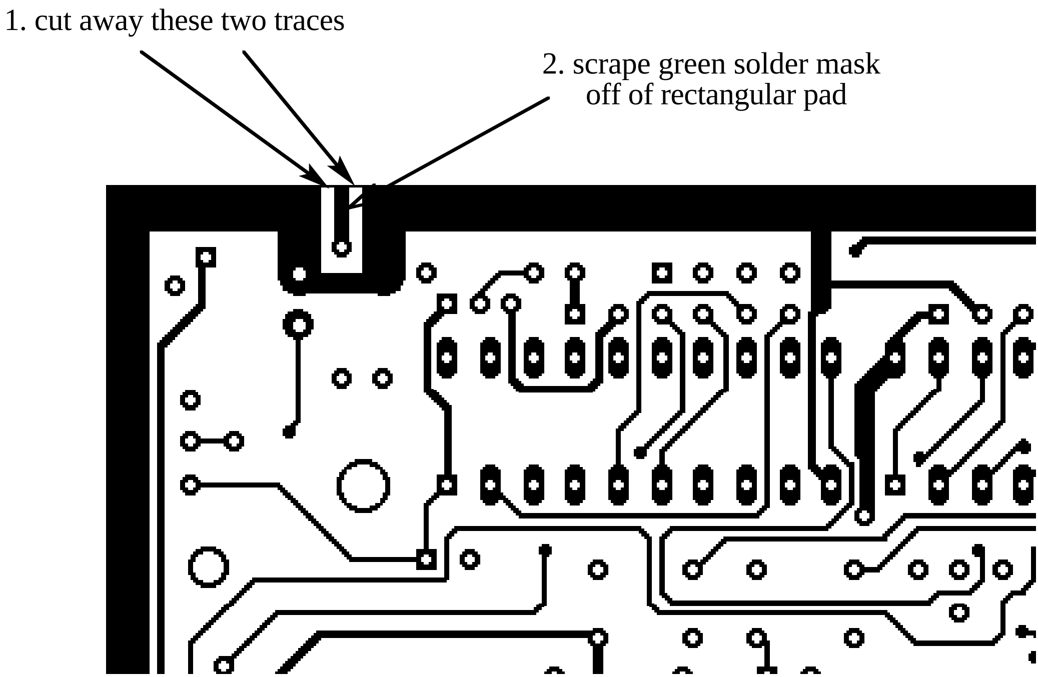
The general strategy for assembling the board should be to mount small flat components (like DIP sockets, resistors, resistor packs, caps, and diodes) first, and thick, clunky components (like switches) last. It's up to you to determine exactly what order you want to do things; most of the time, it shouldn't matter.

The following list tells you some important special cases of component mounting. *Please* read this list before you begin to assemble the board.

## 1–☐ Minor Board Fixes

The solder mask—the green material on the board that keeps the solder from flowing across connections where it shouldn't—needs to be scraped away for the mounting pads for the bend sensors. Also, two thin traces near each mounting pad need to be removed.

See Figure 5 for details. You will probably want to do these fixes before mounting any components.




3. scrape away green solder mask on component side of board directly opposite pad diagrammed in #2;
4. repeat steps 1-3 for all four bend sensor mounting pads.

Figure 5: Bend Sensor Mounting Fixes

## 2–☐ Determine the Component Side

All but two of the components mount on one side of the board. This is the side with the printed component layout information. Mount

components so that their pins go down from this side (e.g., the parts will obscure the printing when they are mounted properly).

Don't blow it and mount everything on the wrong side!! This would be an drastic error.

### 3–☐ Integrated Circuit U3 and DIP socket for U2

Mount **U3** directly to the circuit board. Observe proper polarity—you will have to desolder if you get it wrong! Be careful not to heat the pins for too long. Note that you will have to cut away the center support for the 28-pin DIP socket in order to fit it over U3.

### 4–☐ 6811 Socket

When mounting the square black socket for the 6811, observe the following polarity: Pin one of the socket is labelled either a "1" or "2" on the inside top of the socket. The pin indicated by this marking goes into the square hole on the circuit board.

### 5–☐ Capacitors C1, C2, and C17

These capacitors should be bend over to lie flat on the board before soldering.

### 6–☐ MLED71 Infrared LEDs.

These LEDs are shaped in small rectangular packages. These are all mounted such that the clear bubble (the LED's lens) faces outward from the board, and the brown face with the two colored stripes faces inward. See following comment about **LED22** before installing.

### 7–☐ LED22

This component gets a bit cramped because I underestimated the size of the 4-pin DIP switch (**SW6**). Please mount **LED22** *after* mounting **SW6** and the adjacent **SW7** (the tilt sensor).

### 8–☐ Resistors R3, R7, R12, and R28

These resistors have incorrect values printed on the circuit board. You may want to install these resistors first so you don't get confused. The correct values are: R3=470Ω; R7=470Ω; R12=1kΩ; R28=30Ω, 2 watt.

## 9–☐ Resistor R20 and Diode D8

Resistor **R20** will not be used.

Mount diode **D8** such that it spans over the holes for resistor **R20**. The cathode of the diode mounts in the square hole as marked; the anode mounts in the far hole alloted for **R20**.

## 10–☐ R7 Fix

Firstly, note that **R7** should be 470Ω, *not* 1kΩ as indicated on the board.

To do this fix, you will need to cut a trace and install a jumper wire. You should use an X-acto knife or razor blade to cut the trace. You should use thin wire-wrap wire as the jumper.

**R7** mounts near the miniature speaker. After you have located the resistor, find its mounting hole nearest to the edge of the PC board. Turn the board over: this hole should have a thin wire connecting at right angles to a thicker wire that runs parallel to the edge of the board.

Cut the thin trace connecting **R7** to this thicker trace. *Do not sever the thick trace itself.*

For the jumper, cut a piece of wire-wrap wire about four inches long.

Locate **R1** (near the reset switch). Flip the board over, and observe that one terminal of **R1** connects (via a thick, meandering trace) to pin 5 of **U15**.

Solder one end of the jumper wire to this terminal of **R1**—it is the terminal of **R1** that is farther away from **R7**. Solder the other end of the jumper to the terminal of **R7** that you disconnected (the terminal closer to the edge of the board).

## 11–☐ R30

**R30** (a 47kΩ resistor) was added to the circuitry after the board was designed, so there are no mounting holes for it. Instead, it must be mounted flat against the back of the board. Mount **R30** so that it connects pins 3 and 4 of **U16**.

## 12–☐ RP4 Fix

**RP4** should be a 47kΩ × 4 resistor pack. If you have a resistor pack that is 47kΩ × 5, you must clip off the last resistor. Cut off one resistor from the *unbanded end* before mounting.

### 13–☐ U8 Serial Line Fix

Using a short wire jumper, connect pins 1 and 3 of **U8** (do this on the underside of the board).

### 14–☐ Resistor R22 and Diodes D3 and D9

These devices are not needed. Do not mount any components in the holes alloted for them.

### 15–☐ Photocells VR3 and VR4

These should be mounted so that they face over the front diagonal corners of the board. Bend the leads at right angles as near to the case as possible; after you solder them in, you can twist them slightly toward their respective corner of the board. *Be very careful to apply as little heat as possible when soldering; photocells are* extremely *sensitive to heat.*

### 16–☐ Missing Trace on RP2

The square terminal of **RP2** needs to be connected to pin 20 of **U7** (the IC pin to which the RP2 terminal is nearest). Use a discarded piece of component lead to make this connection.

### 17–☐ Sharp IR Sensors

Before mounting each Sharp IR sensor (**IR-1** through **IR-4**), put small pieces of electrical tape on the board to insulate the board from the supporting metal sides of the Sharp sensors. Note that sensors **IR-2** and **IR-4** mount underneath the board.

### 18–☐ D10, the TIL-99

This component must be bent over to point toward **LED21** before soldering. The lead near the metal tab of the transistor mounts in the square hole.

## 19–☐ Female Socket Header

Cut strips of socket header to mount in the Expansion Bus area (a 14-long strip and a 9-long strip), the lower motor ports adjacent to **U18** (a 6-long strip), and the Batt Out port (a 2-long strip).

## 20–☐ RJ-11 Phone Jack

The phone jack mounts on the top of the board; unfortunately, the pinout drilled into the board has a symettry problem. *Do not mount the jack from the underside of the board.* Instead, bend the pins of the jack before insertion such that they will fit into the holes that are drilled.

## 21–☐ Preparing the LCD Display

Cut a 14-long strip of male socket header. Insert the short pins of the header up from the underside of the LCD connector holes. Solder from the top of the LCD display.

## 22–☐ Mounting the Bend Sensors

Figure 6 shows how to mount the bend sensors. You may wish to see this done in person before you go ahead and mount them.

## 23–☐ Heatsink Mounting on U18

Slide one of the gold heatsinks onto **U18** (L293D) before mounting it into its socket. Be sure to keep track of the pin one orientation after you've slid on the heatsink.

## 24–☐ Piggy-backing the L293 Chips

Motor driver chips **U17** (L293D) and **U19** (L293B) will be piggy-backed and soldered together before installing in their socket.

To perform this operation, begin by sliding the gold-colored heat sink over **U19**. Then, press **U19** over **U17**, as indicated in Figure 7. Make sure to that you have the two chips in the same "pin one" orientation with respect to each other! Then, solder them together. Try to have them pressed together as closely as possible, firmly against the heat sink.

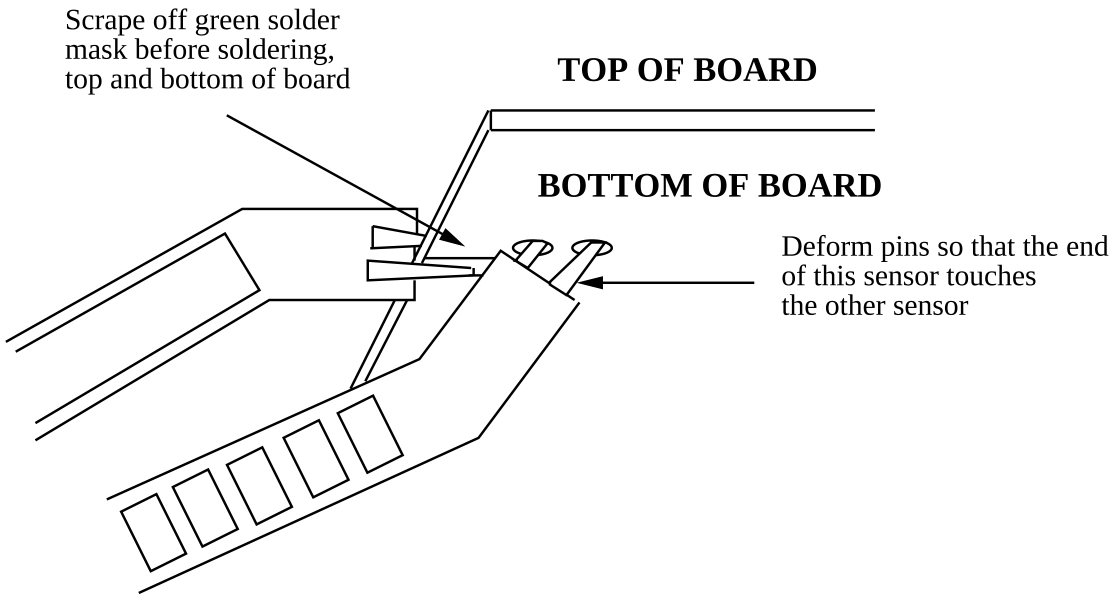



Figure 6: Bend Sensor Mounting Technique

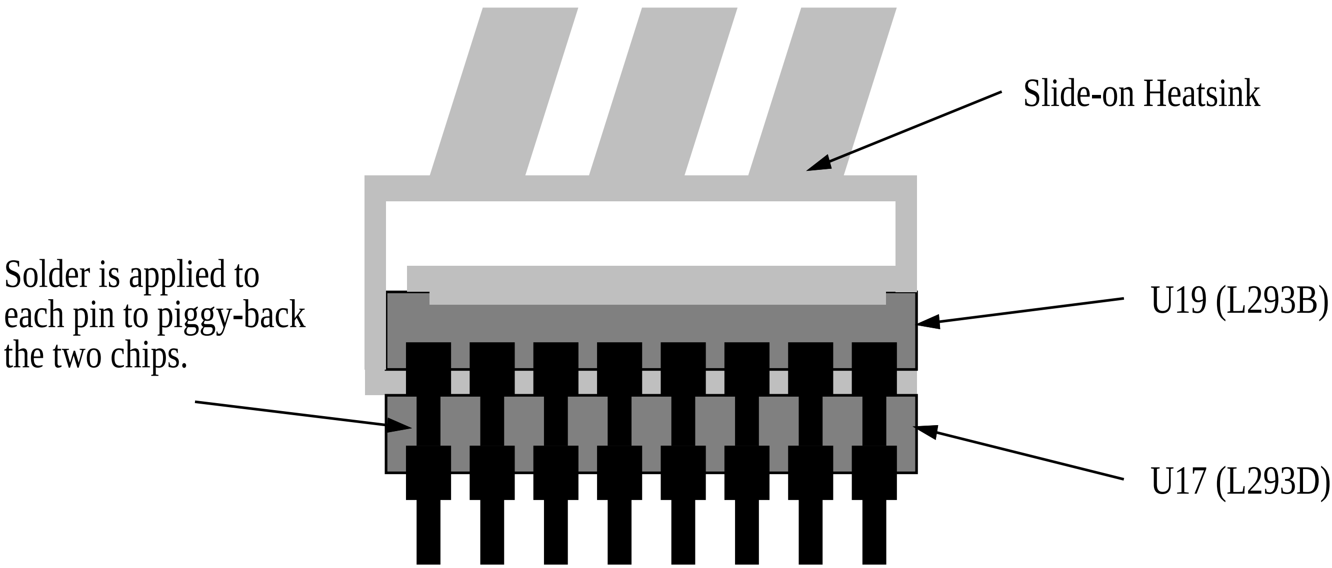



Figure 7: Motor Chip Stacking Technique

## B.3 Check-off Parts Listing

This parts listing may be used as a quick reference when assembling the board. If you wish, use this list to check off each component after it is mounted.

Instead of mounting components in order of their numbering, you may be able to save time by selecting a component to be mounted on the board, and then looking up its value here.

Note: if there is a discrepancy between the component value printed on the board and the component value listed here, the value listed here are correct. A complete list of the discrepancies was included earlier in the assembly directions for the particular components that have new values.

### B.3.1 Integrated Circuit Sockets

| | | |
|---|---|---|
| ○ **U1**–52-pin PLCC | ○ **U2**–28-pin DIP | ○ **U3**–*none–special!* |
| ○ **U4**–16-pin DIP | ○ **U5**–20-pin DIP | ○ **U6**–20-pin DIP |
| ○ **U7**–20-pin DIP | ○ **U8**–16-pin DIP | ○ **U9**–14-pin DIP |
| ○ **U10**–14-pin DIP | ○ **U11**–14-pin DIP | ○ **U12**–16-pin DIP |
| ○ **U13**–16-pin DIP | ○ **U14**–16-pin DIP | ○ **U15**–8-pin DIP |
| ○ **U16**–8-pin DIP | ○ **U17**–16-pin DIP | ○ **U18**–16-pin DIP |
| ○ **U19**–*none–special!* | ○ **U20**–20-pin DIP | ○ **U21**–20-pin DIP |

### B.3.2 Resistors

All resistors are $\frac{1}{8}$ watt, unless otherwise noted.

| | | |
|---|---|---|
| ○ **R1**–5Ω, 1W | ○ **R2**–100Ω | ○ **R3**–470Ω |
| ○ **R4**–1kΩ | ○ **R5**–1kΩ | ○ **R6**–1kΩ |
| ○ **R7**–470Ω | ○ **R8**–1kΩ | ○ **R9**–1kΩ |
| ○ **R10**–2.2kΩ | ○ **R11**–2.2kΩ | ○ **R12**–1kΩ |
| ○ **R13**–2.2kΩ | ○ **R14**–2.2kΩ | ○ **R15**–10kΩ |
| ○ **R16**–10kΩ | ○ **R17**–10kΩ | ○ **R18**–10kΩ |
| ○ **R19**–10kΩ | ○ **R20**–not used | ○ **R21**–47kΩ |
| ○ **R22**–not used | ○ **R23**–47kΩ | ○ **R24**–47kΩ |
| ○ **R25**–47kΩ | ○ **R26**–100kΩ | ○ **R27**–2.2MΩ |
| ○ **R28**–30Ω, 2W | ○ **R29**–3.3kΩ | ○ **R30**–47kΩ |

### B.3.3 Resistor Packs and Trimpots

All resistor packs are common ground, unless otherwise noted.

○ **RP1**–47kΩ × 9
○ **RP2**–47kΩ × 9
○ **RP3**–47kΩ × 7
○ **RP4**–47kΩ × 5
○ **RP5**–1kΩ × 5
○ **RP6**–22kΩ × 5 iso
○ **VR1**–100kΩ
○ **VR2**–100kΩ

### B.3.4 Capacitors

○ **C1**–330 μF
○ **C2**–1 μF
○ **C3**–0.1 μF
○ **C4**–0.1 μF
○ **C5**–0.1 μF
○ **C6**–0.1 μF
○ **C7**–0.1 μF
○ **C8**–0.1 μF
○ **C9**–0.1 μF
○ **C10**–0.1 μF
○ **C11**–0.1 μF
○ **C12**–2.2 μF
○ **C13**–4.7 μF
○ **C14**–4.7 μF
○ **C15**–10 μF
○ **C16**–10 μF
○ **C17**–47 μF
○ **C18**–4700 pF
○ **C19**–22 pF
○ **C20**–22 pF

### B.3.5 Transistors

○ **Q1**–MPS2222A
○ **Q2**–MPS2222A
○ **Q3**–MPS2222A

### B.3.6 Diodes

○ **D1**–1N4001
○ **D2**–1N4001
○ **D3**–not used
○ **D4**–1N4148
○ **D5**–1N4148
○ **D6**–1N4148
○ **D7**–1N4148
○ **D8**–1N4148
○ **D9**–not used

### B.3.7 LEDs

○ **LED1**–red
○ **LED2**–red
○ **LED3**–red
○ **LED4**–red
○ **LED5**–red
○ **LED6**–red

○ **LED7**–red
○ **LED8**–green
○ **LED9**–green
○ **LED10**–green
○ **LED11**–green
○ **LED12**–green
○ **LED13**–green
○ **LED14**–yellow
○ **LED15**–yellow
○ **LED16**–MLED71
○ **LED17**–MLED71
○ **LED18**–MLED71
○ **LED19**–MLED71
○ **LED20**–MLED71
○ **LED21**–MLED71
○ **LED22**–MLED71
○ **LED23**–MLED71

### B.3.8 Miscellaneous Components

○ **XTAL**–8 Mhz crystal
○ **SPKR**–miniature speaker element
○ **L1**–1$\mu$H, 1A inductor
○ **L2**–1$\mu$H, 1A inductor

### B.3.9 Switches

○ **SW1**–toggle switch
○ **SW2**–slide switch
○ **SW3**–red button
○ **SW4**–micro button
○ **SW5**–micro button
○ **SW6**–4-pin DIP
○ **SW7**–large microswitch
○ **SW8**–large microswitch
○ **SW9**–large microswitc
○ **SW10**–large microswitch

### B.3.10 Integrated Circuits

○ **U1**–68HC11A0
○ **U2**–60LP256
○ **U3**–74HC373
○ **U4**–74HC138
○ **U5**–74HC374
○ **U6**–74HC244
○ **U7**–74HC244
○ **U8**–74HC4053
○ **U9**–74HC10
○ **U10**–74HC132
○ **U11**–74HC04
○ **U12**–74HC390
○ **U13**–74HC4051
○ **U14**–74HC4051
○ **U15**–LM386
○ **U16**–LM358
○ **U17**–L293D
○ **U18**–L293D
○ **U19**–L293B
○ **U20**–74HC244
○ **U21**–74HC374

### B.3.11 Sensors

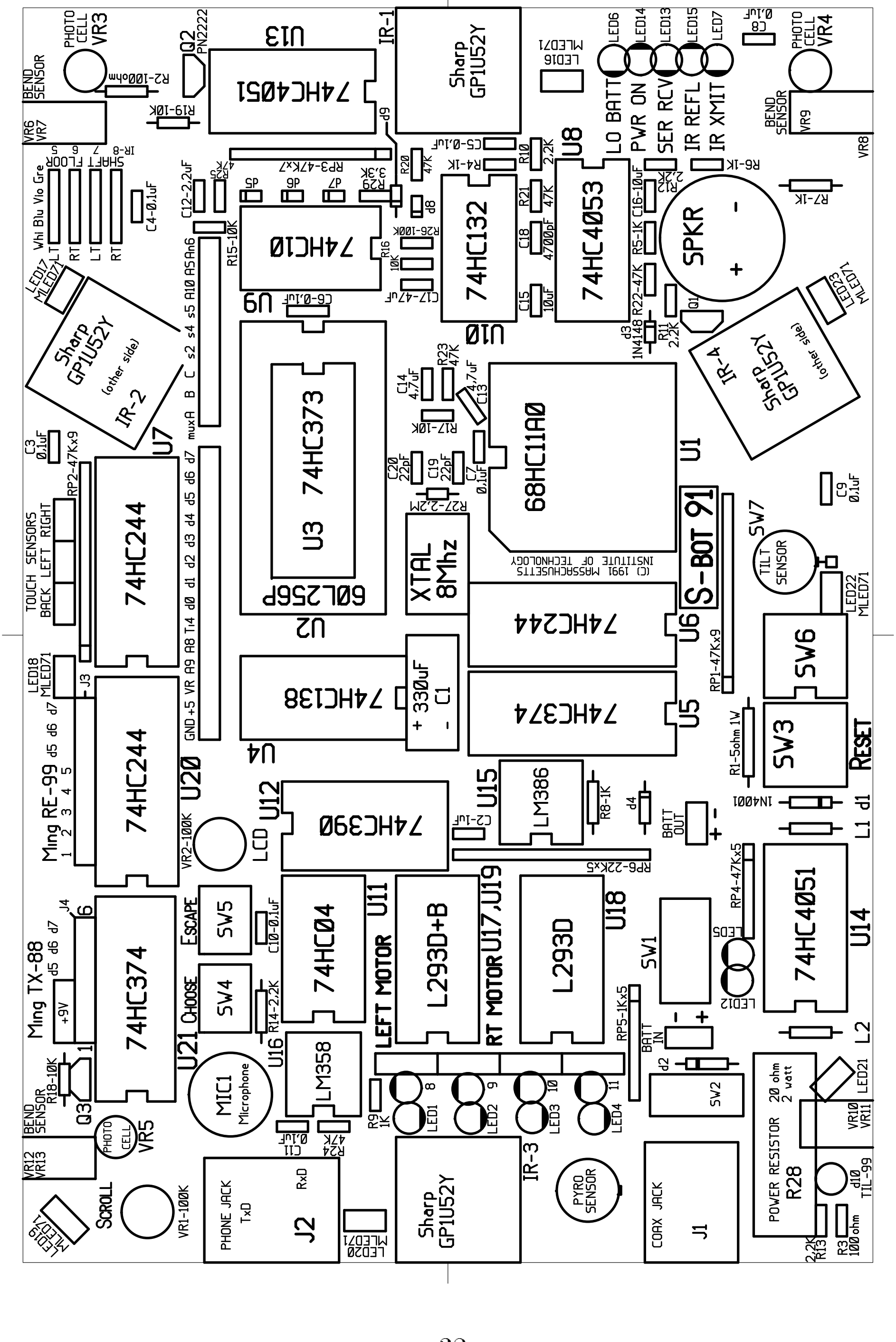
○ **IR-1**–Sharp GP1U52Y
○ **IR-2**–Sharp GP1U52Y
○ **IR-3**–Sharp GP1U52Y
○ **IR-4**–Sharp GP1U52Y
○ **IR-5**–TRW OPB 5447-2
○ **IR-6**–TRW OPB 5447-2

- ◯ **IR-7**–TRW OPB 5447-2
- ◯ **IR-8**–TRW OPB 5447-2
- ◯ **VR3**–CdS photocell
- ◯ **VR4**–CdS photocell
- ◯ **VR5**–CdS photocell
- ◯ **VR6**–bend sensor
- ◯ **VR7**–bend sensor
- ◯ **VR8**–bend sensor
- ◯ **VR9**–bend sensor
- ◯ **VR10**–bend sensor
- ◯ **VR11**–bend sensor
- ◯ **VR12**–bend sensor
- ◯ **VR13**–bend sensor
- ◯ **D10**–TIL-99 phototransistor
- ◯ **PYRO**–Eltec 447 pyroelectric sensor
- ◯ **MIC**–electret condensor microphone

### B.3.12 Connectors

- ◯ **J1**–DC power jack, 2.1mm ID
- ◯ **J2**–RJ11 right angle jack
- ◯ **J3**–8-pin right angle Molex
- ◯ **J4**–6-pin right angle Molex
- ◯ **J5**–9 volt battery snap

## B.4 Board Parts Layout



# C Mechanical Assembly Guide

This guide will tell you how to assemble the Sensor Robot's chassis, wire the touch sensors, and wire and install the motor/gearbox/wheel assembly.

## Instructions

*Please read through these instructions from start to finish before building anything!! If something is unclear, you may wish to ask about it before doing it wrong.*

**1–☐ Preparing the Gearbox.**

- ◯ Take apart the Red Fox car and remove the gearbox assembly. There is a hidden screw that you must remove in order to take the car apart without breaking it. The screw is located in the "driver's cockpit" of the car, between the stickers labelled "Radio Shack" and "23." After you remove the gearbox, clip the wires short.
- ◯ Desolder the wires connecting to the motors, and solder a new set of four wires to the motors. Leave at least 12 inches in length to these new leads.

**2–☐ Understanding the Chassis.**

- ◯ The chassis should be oriented so that the folded edges face downward.
- ◯ Any wires going from the PC board to the chassis (motor wires, battery wires, sensor wires) are inserted into the underside of the PC board.
- ◯ Wires going underneath the chassis (e.g., the motor wires and battery wires) enter through the oval hole on the chassis.

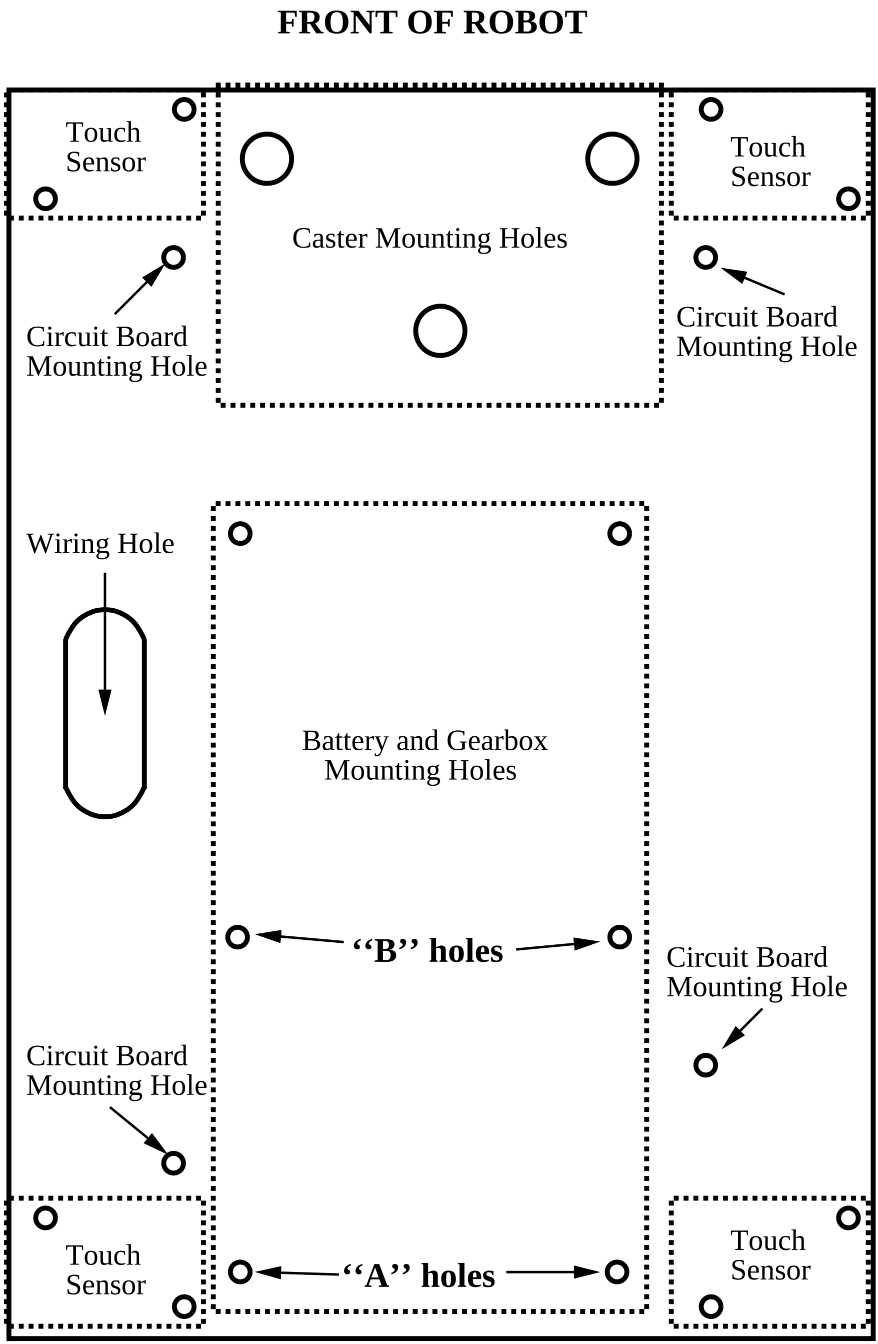



Figure 8: Robot Chassis with Part Mounting Information, Top View

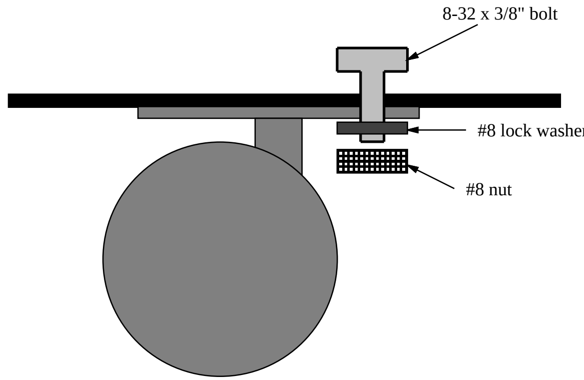



Figure 9: Caster Mounting Guidelines, Side View

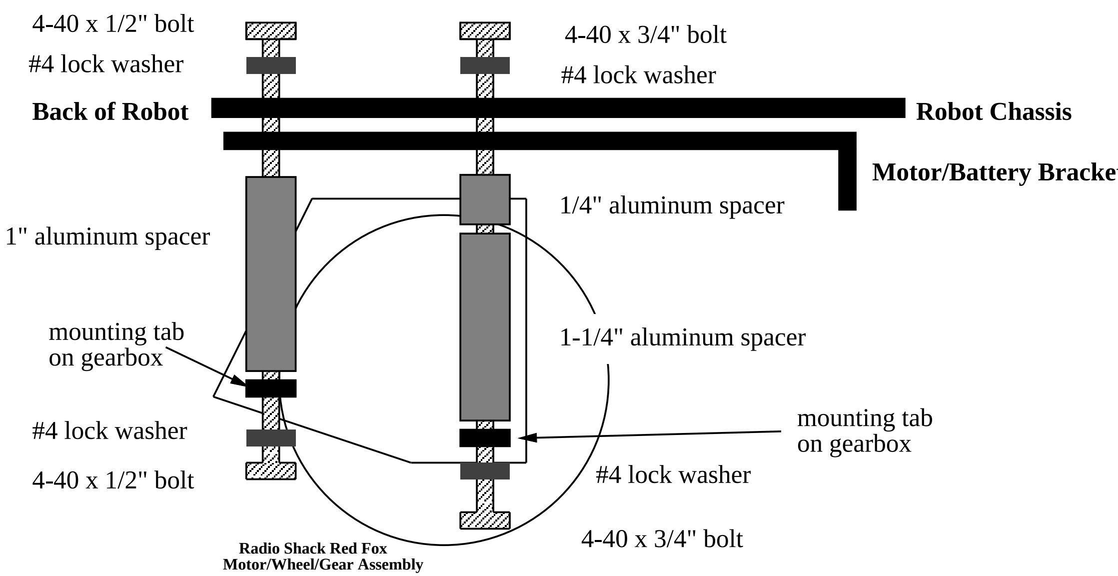



Figure 10: Gearbox Mounting Guidelines, Side View

### 3–☐ Mounting the Caster.

Begin your assembly by mounting the caster in the position indicated by Figure 8. Use the 8-32 bolts, lock washers and nuts as indicated by Figure 9.

### 4–☐ Mounting the Gearbox Supports

Install the 1" aluminum spacers and $1\frac{1}{4}$" + $\frac{1}{4}$" spacers that will support the gearbox assembly. *Do not install the gearbox at this time.*

The two 1" spacers mount in the holes labelled "A" in Figure 8. The two $1\frac{1}{4}$" + $\frac{1}{4}$" spacer assemblies mount in the holes labelled "B."

Refer to Figure 10 for details about how to install the spacers.

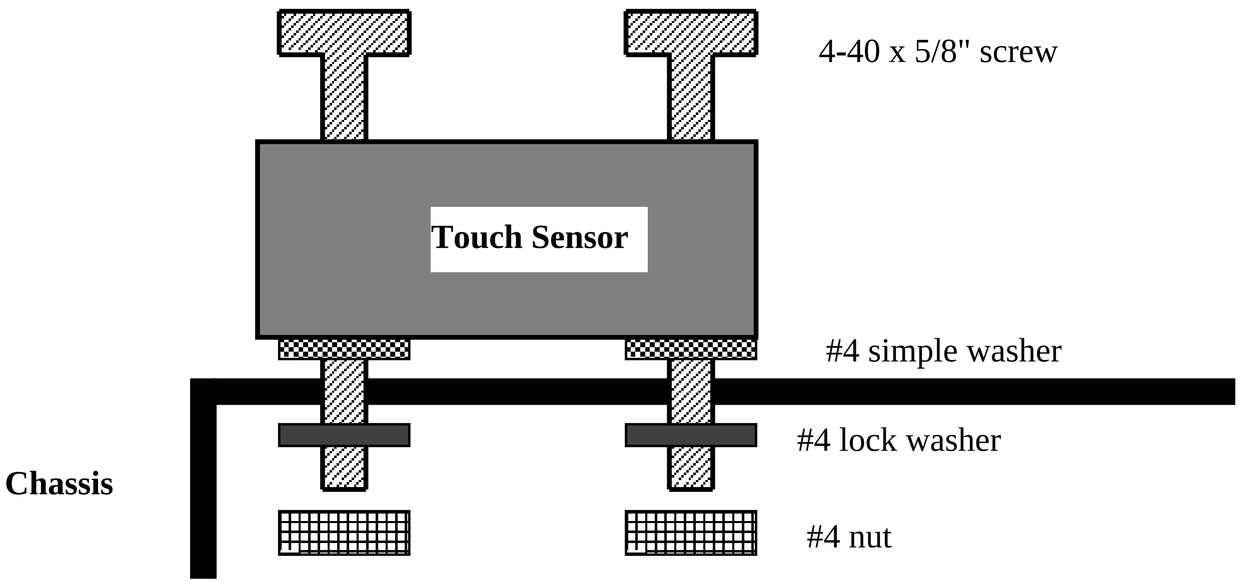



Figure 11: Touch Sensor Mounting Guidelines, Side View

### 5–☐ Mounting the Touch Sensors

Mount the four touch sensors in the positions indicated in Figure 12. Use the guidelines indicated in Figure 11 to select the combination of bolts, nuts, and washers for proper mounting.

## 6–☐ Wiring the Touch Sensors

Following the wiring diagram in Figure 12, wire the touch sensors to the Sensor Robot board. *Insert the wires from the back of the board, and leave enough wire length so that the PC board can lie flat next to the chassis after you are done.*

## 7–☐ Installing the Gearbox

Referring again to Figure 10, bolt in the gearbox/motor/wheel assembly. Thread the 4-wire cable up through the oval mounting hole.

## 8–☐ Soldering the Motor Wires to the PC Board

The goal here is to correctly wire the motors to the PC board. If you get it wrong, when the software tells your robot to go forward, it will end up turning right or going backward or something else.

You need your battery hooked up to do this. Go ahead and route your battery cable through the oval hole and connect the battery.

Turn on your board and *do not* press reset. The motor outputs labelled LEFT MOTOR should have a red LED lit, and the RIGHT MOTOR outputs should have a green LED lit. If this is not the case, turn your board off, wait thirty seconds, and try again.

When you get the proper state, find the wires that connect to the motor driving the *left wheel*. Your goal is to wire these to the LEFT MOTOR port so that when the red LED is lit, the left wheel is turning such that the robot moves in a counterclockwise, backward pivot.

Insert the wires without soldering and see which way the wheel turns. When you get the polarity right, solder the left motor wires in place. *Make sure that you insert the wires from underneath the board, and that the wires are threaded through the oval hole.*

Now, it's time for the right wheel motor. Your goal is to wire this motor such that when the green LED is lit, the robot moves in a counterclockwise, forward pivot. Do it.

## 9–☐ Mounting the PC Board to the Chassis

Follow the instructions given in Figure 13 to mount the circuit board to the chassis. There are four mounting points as indicated in Figure 8.

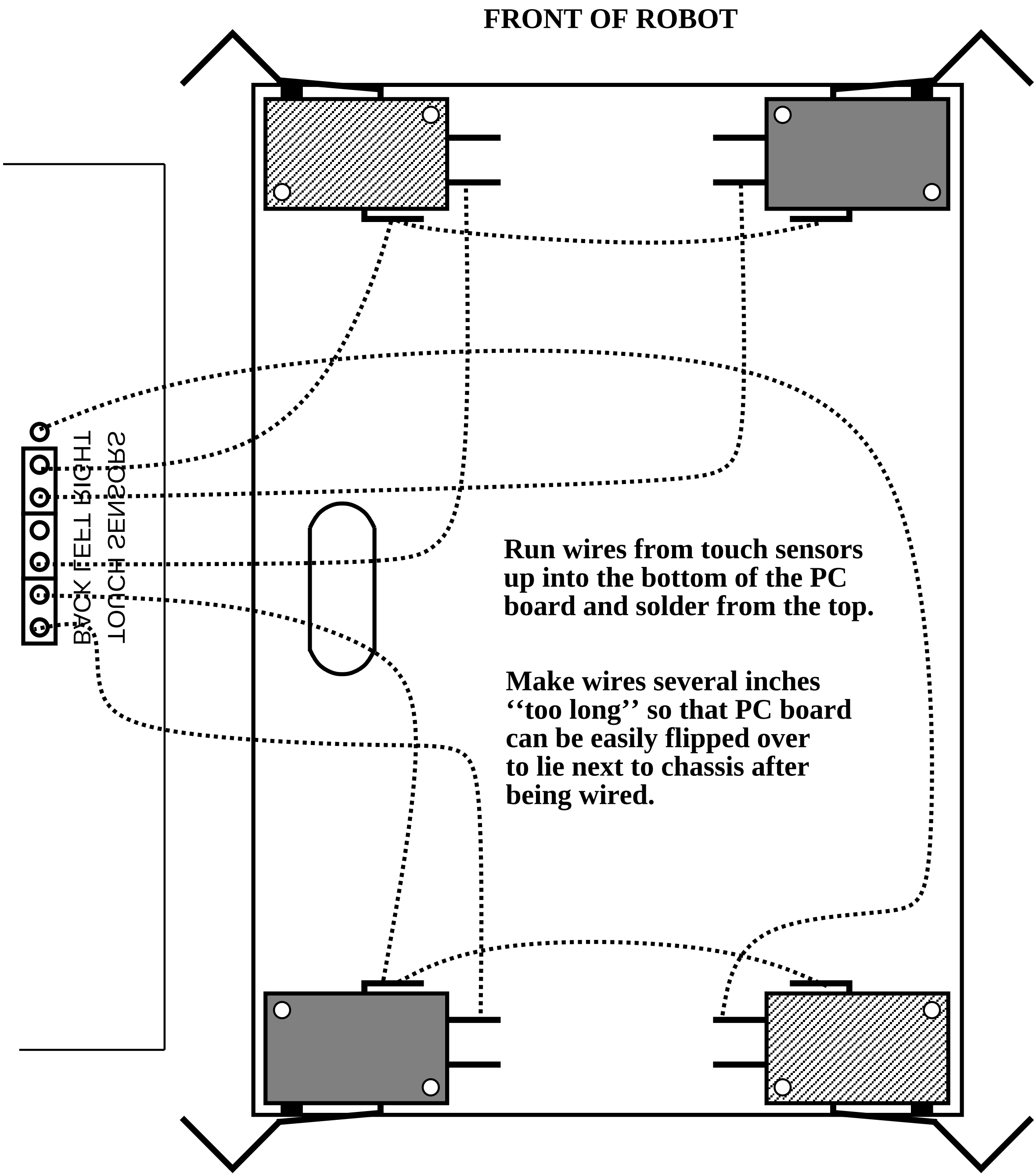



Figure 12: Touch Sensor Wiring Guidelines, Top View

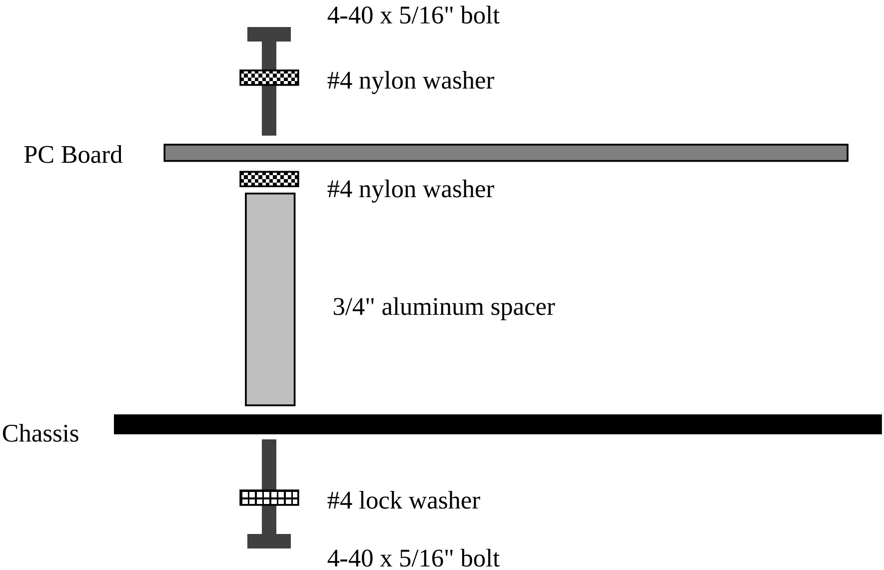



Figure 13: PC Board Mounting Guidelines, Side View

## 10–☐ You Are Done

For now, at least. Parts that will be mounted later are: frame to support axles and hold battery, IR reflectance sensors, IR shaft encoders, and bend sensors.

(You can use a rubber band to hold your battery to the chassis of the 'bot until the support frame is ready.)